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(54) **GAS TURBINE ENGINES WITH INTERNALLY STRETCHED TIE SHAFTS**

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F01D 5/06	(2006.01)
F01D 5/00	(2006.01)
F04D 29/32	(2006.01)
F01D 5/02	(2006.01)

(52) **U.S. Cl.**

CPC ***F01D 5/066*** (2013.01); ***F01D 5/005*** (2013.01); ***F01D 5/025*** (2013.01); ***F01D 5/026*** (2013.01); ***F04D 29/321*** (2013.01); *F05B 2260/301* (2013.01); *F05D 2220/32* (2013.01); *F05D 2230/60* (2013.01); *F05D 2230/70* (2013.01); *F05D 2230/72* (2013.01); *F05D 2240/24* (2013.01); *F05D 2240/61* (2013.01); *F05D 2250/281* (2013.01); *F05D 2260/31* (2013.01)

(58) **Field of Classification Search**

CPC F01D 5/066; F01D 5/026; F01D 5/005; F05B 2260/301; F05D 2230/60; F05D 2240/24; F05D 2230/72; F05D 2230/70; F05D 2220/32; F05D 2240/61

See application file for complete search history.

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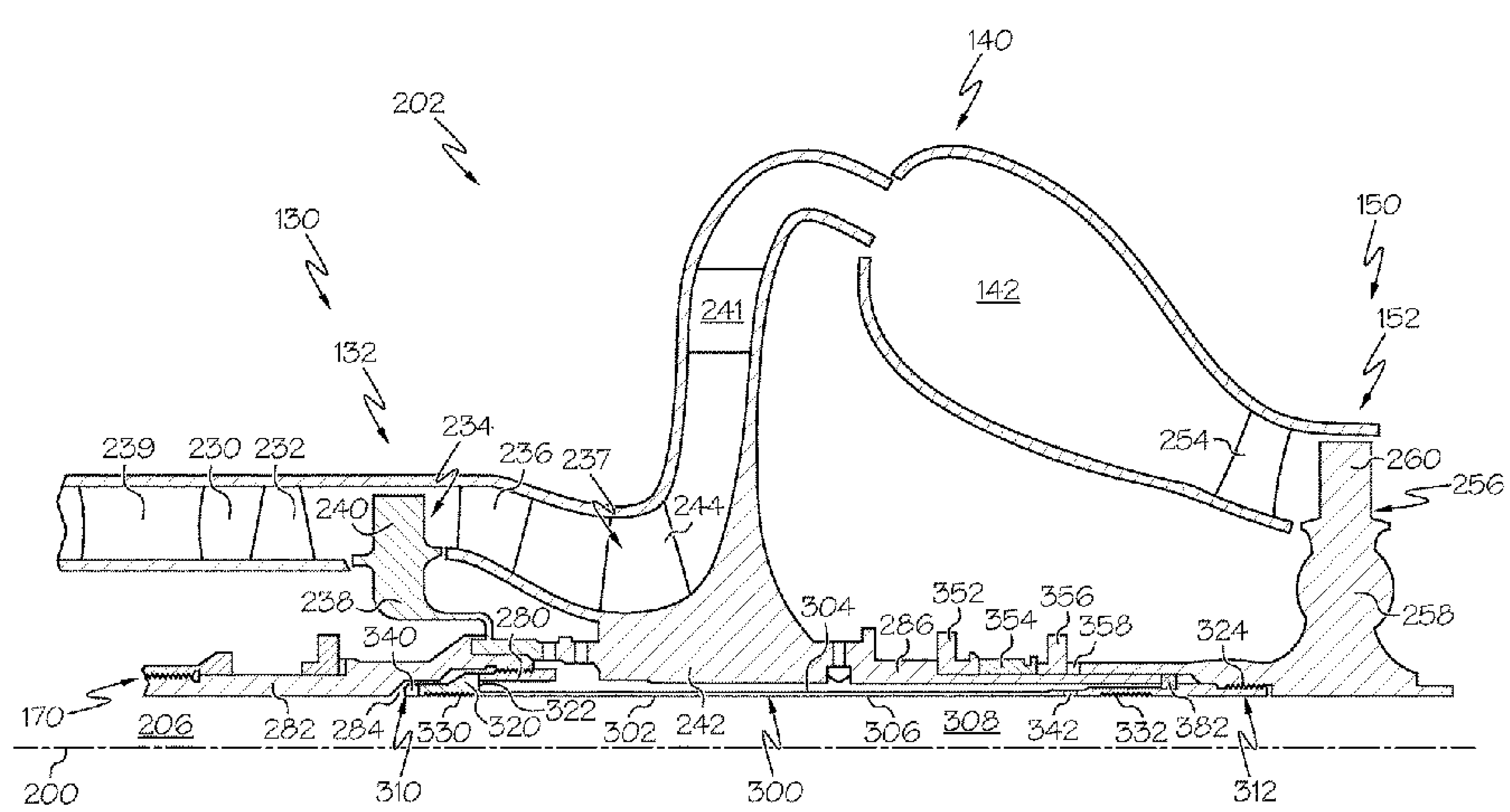
(57) **ABSTRACT**

A tie shaft for a rotating group of an engine core includes a cylindrical body having an internal surface and an external surface and extending between a forward end and an aft end. The tie shaft further includes a first group of internal grooves on the internal surface of the cylindrical body proximate to the forward end and a second group of internal grooves on the internal surface of the cylindrical body proximate to the aft end.

16 Claims, 14 Drawing Sheets



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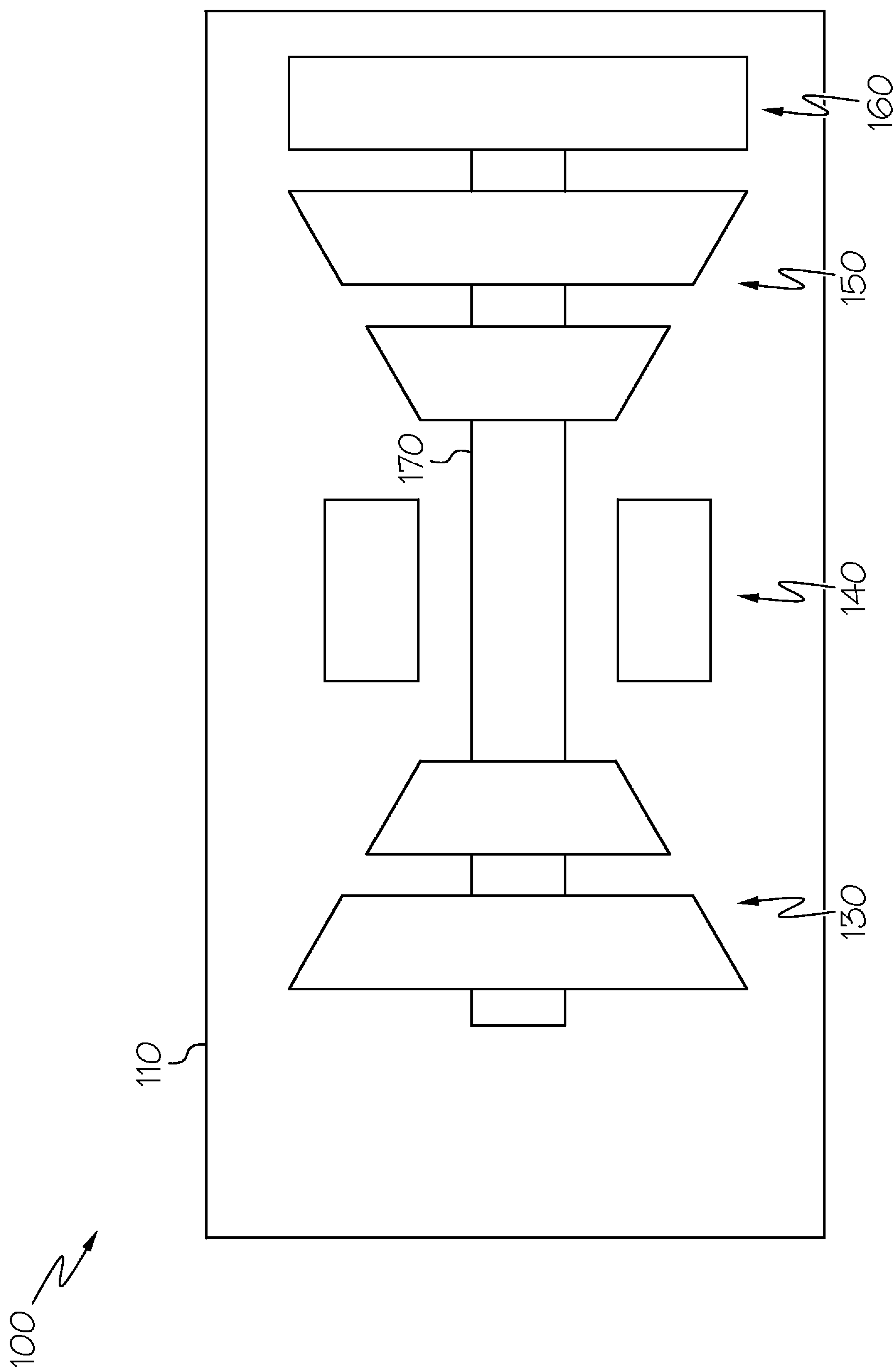

FIG. 1

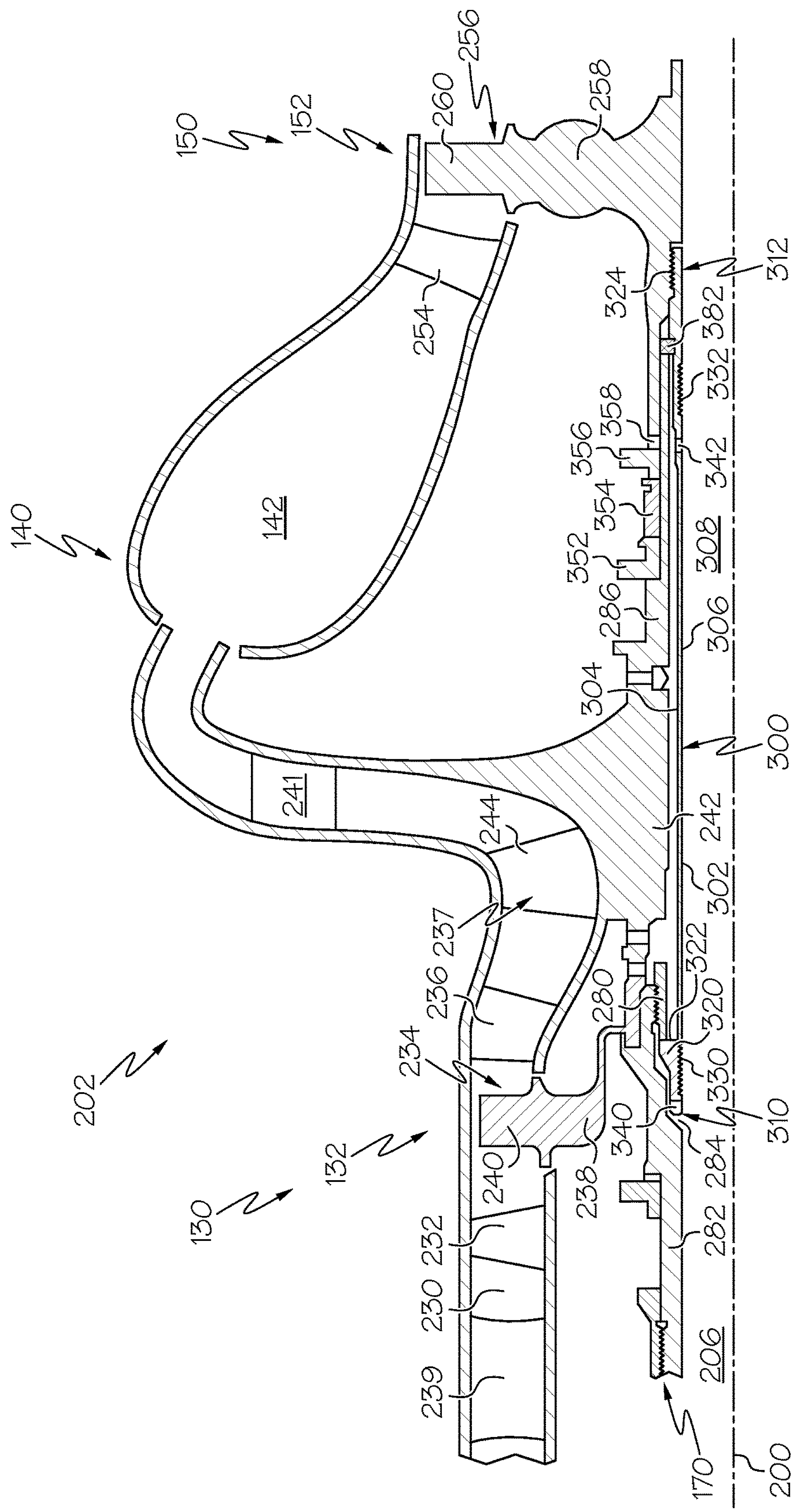
150
152
256
260
258
254
142
140
324
312
382
332
358
356
342
354
352
308
286
306
304
300
241
244
242
302
237
236
322
280
320
330
234
202
310
340
132
240
238
284
130
232
282
230
206
239
170
200

FIG. 2

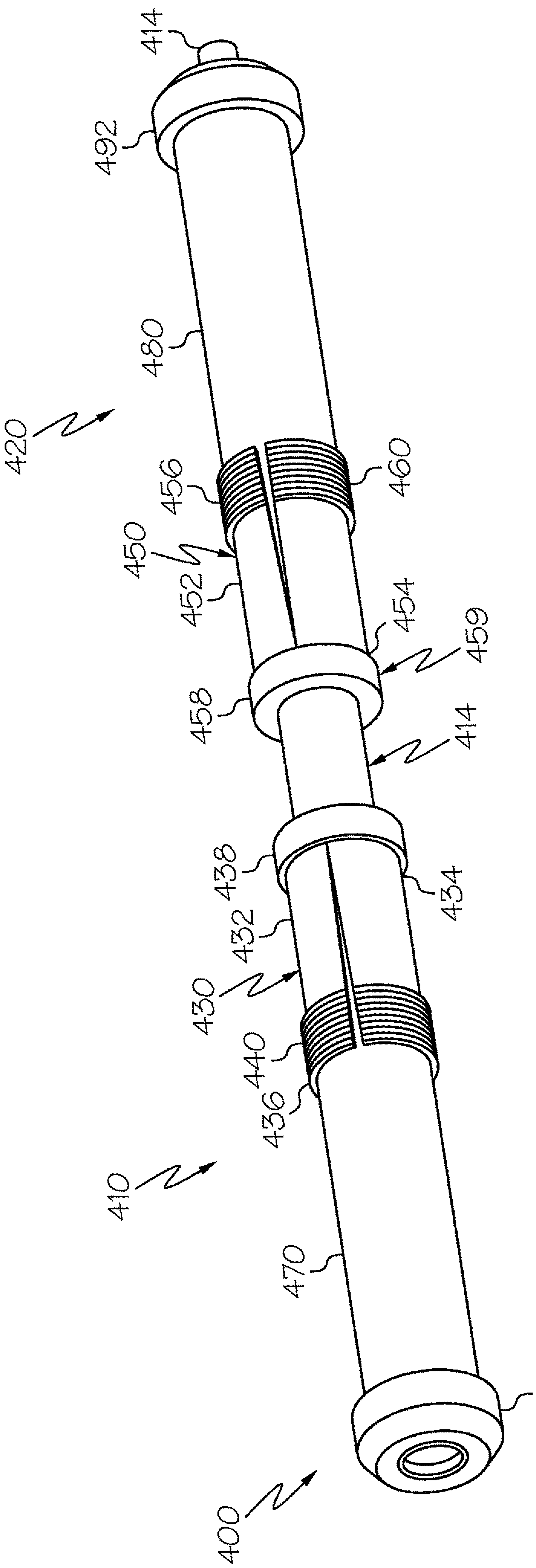
414
492
480
420
456
460
450
452
454
459
458
414
438
434
432
430
440
436
410
470
490
400

FIG. 3

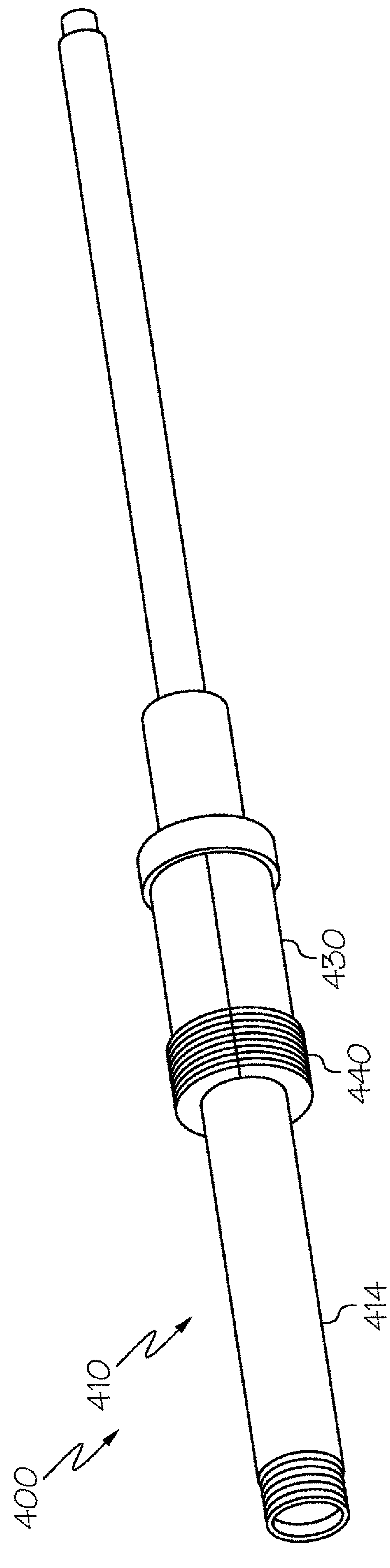

FIG. 4

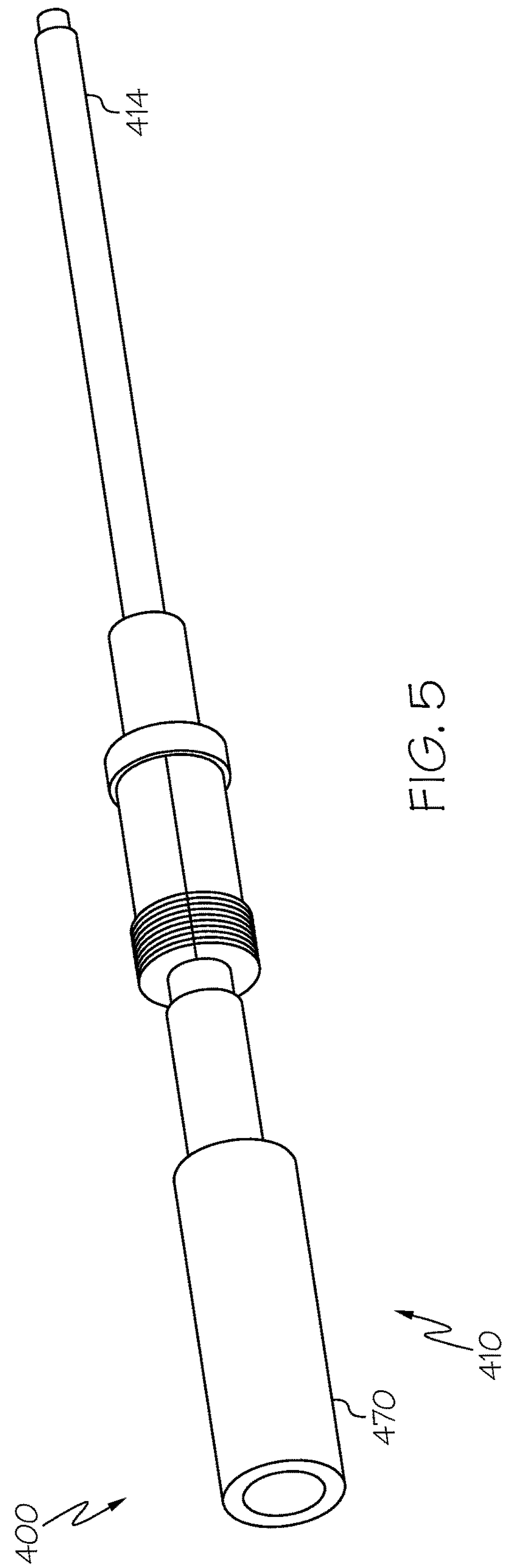

FIG. 5

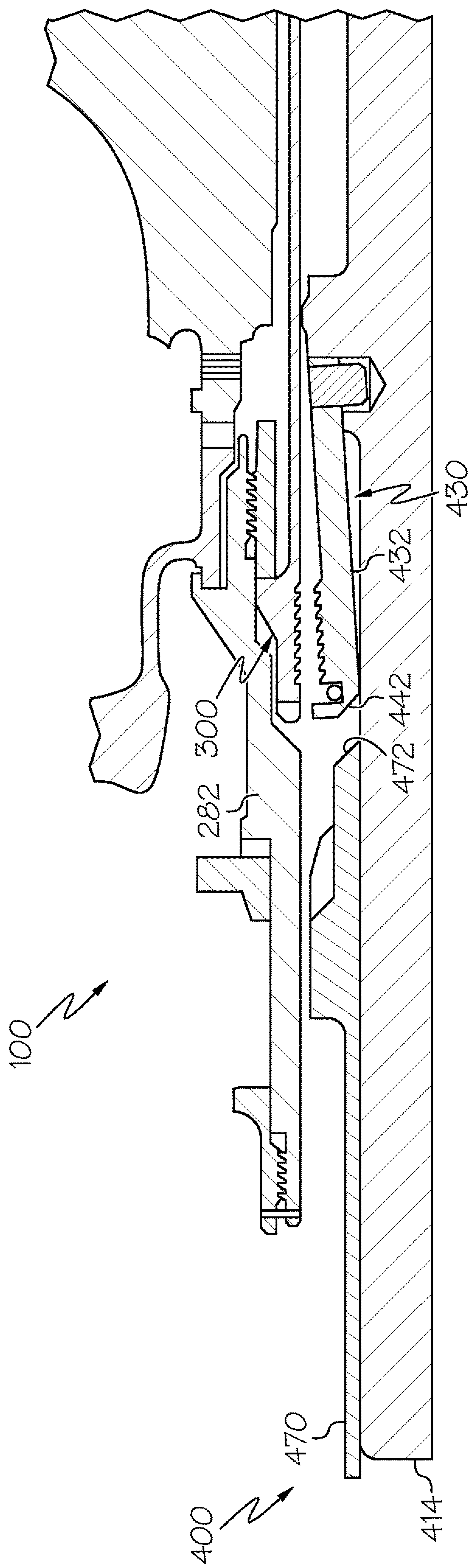

FIG. 6

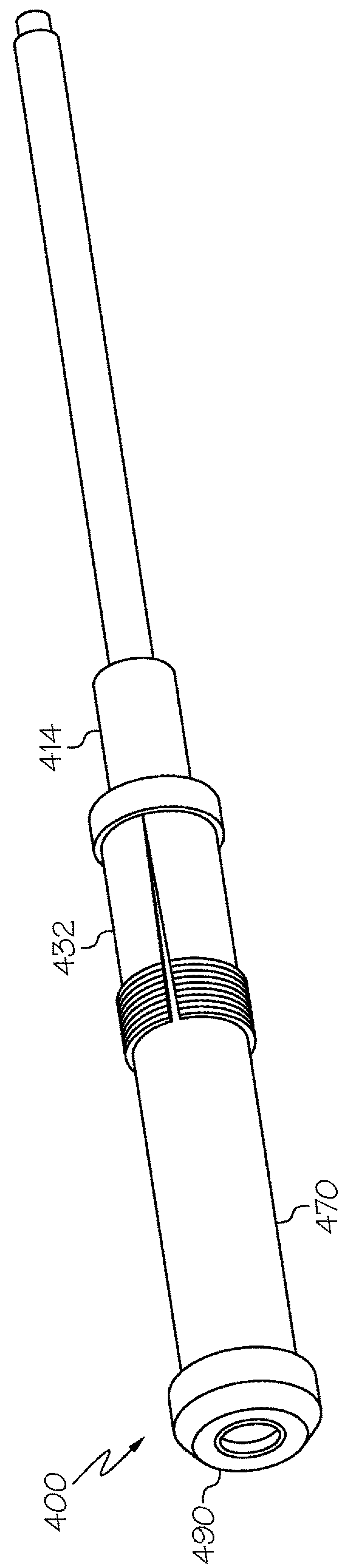

FIG. 7

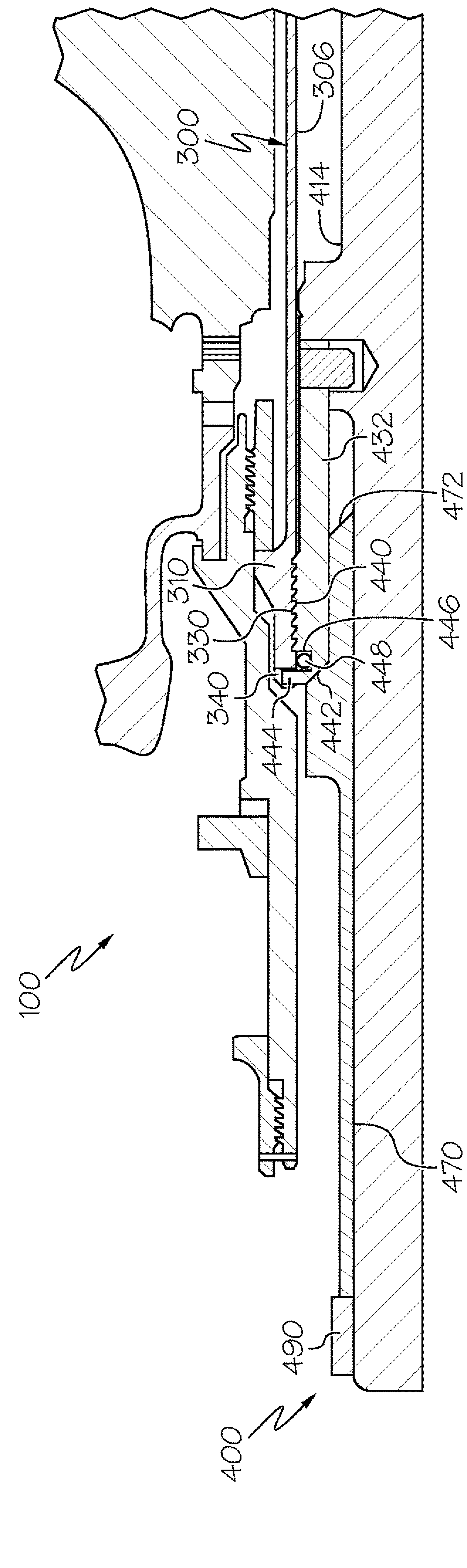
306
300
414
432
472
440
310
446
330
448
340
442
444
100
470
490
400

FIG. 8

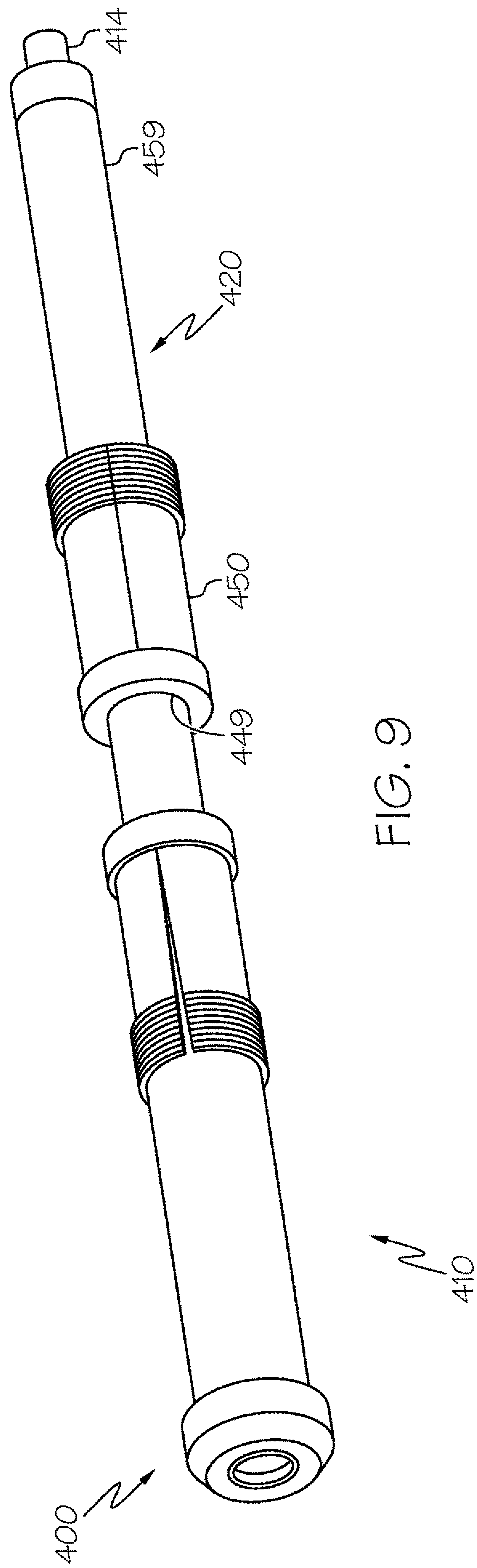

FIG. 9

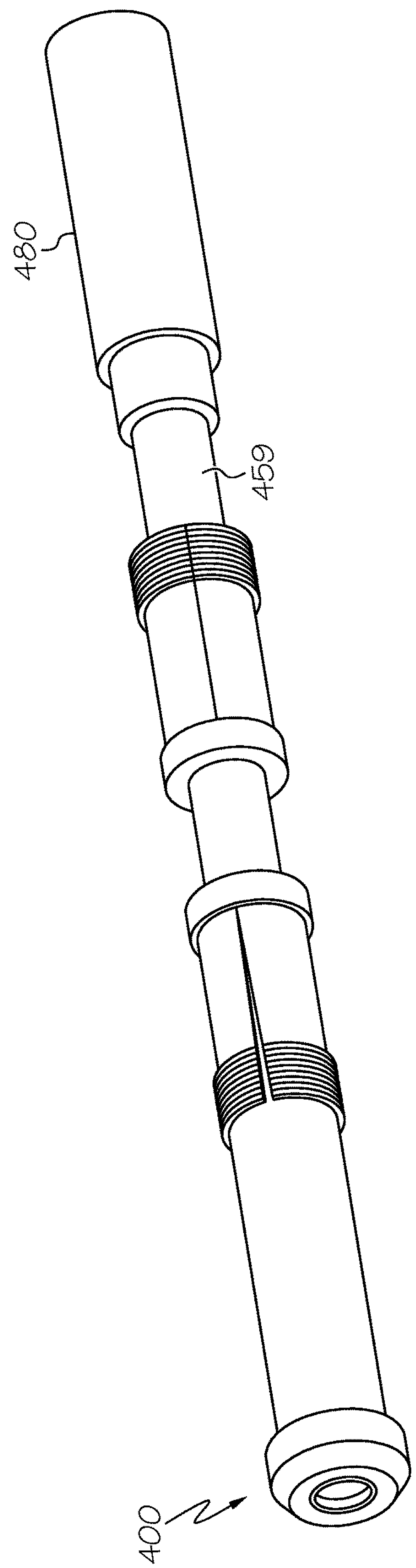

FIG. 10

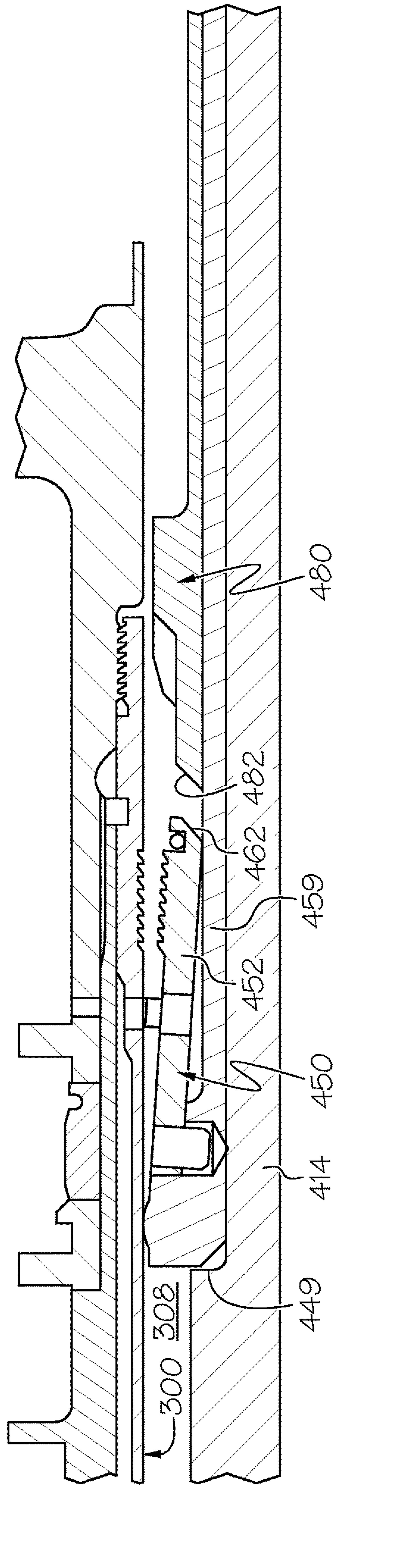

FIG. 11

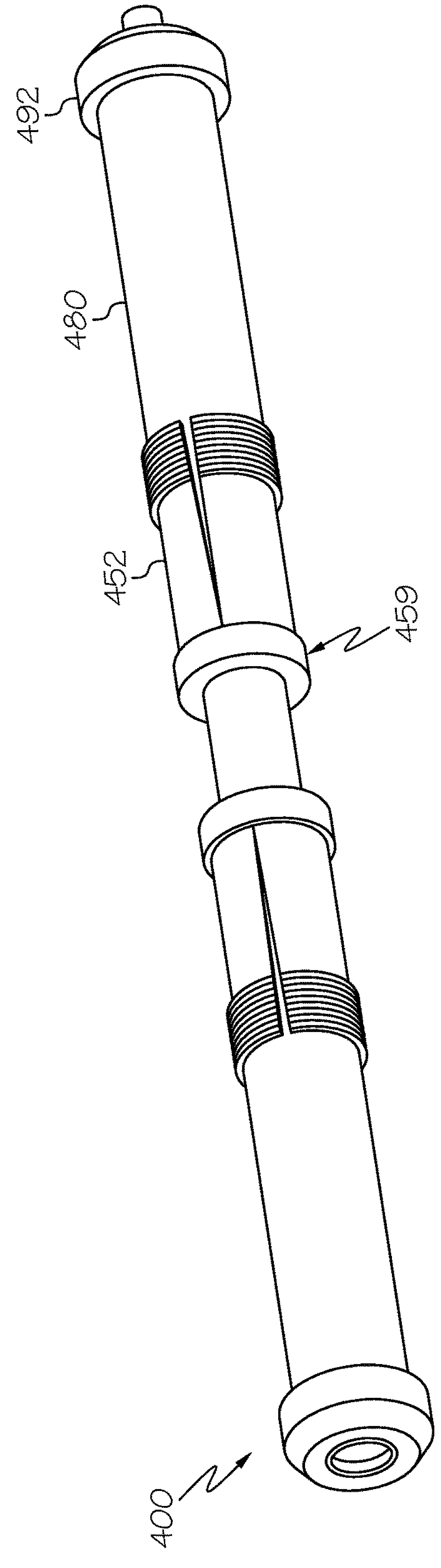

FIG. 12

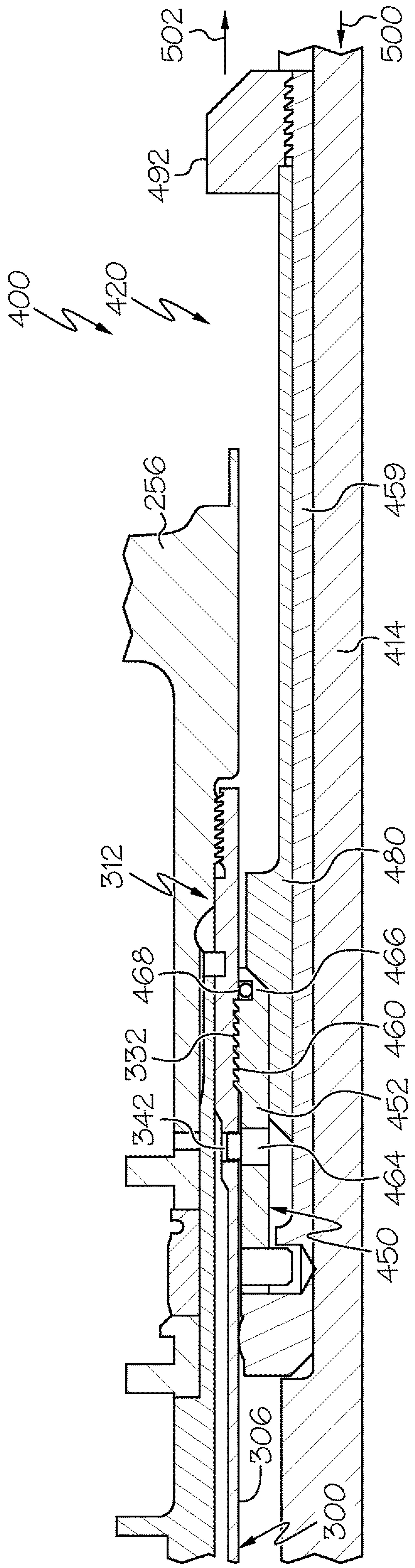
502
500
492
400
420
256
459
414
480
312
466
468
460
332
452
342
464
450
306
300

FIG. 13

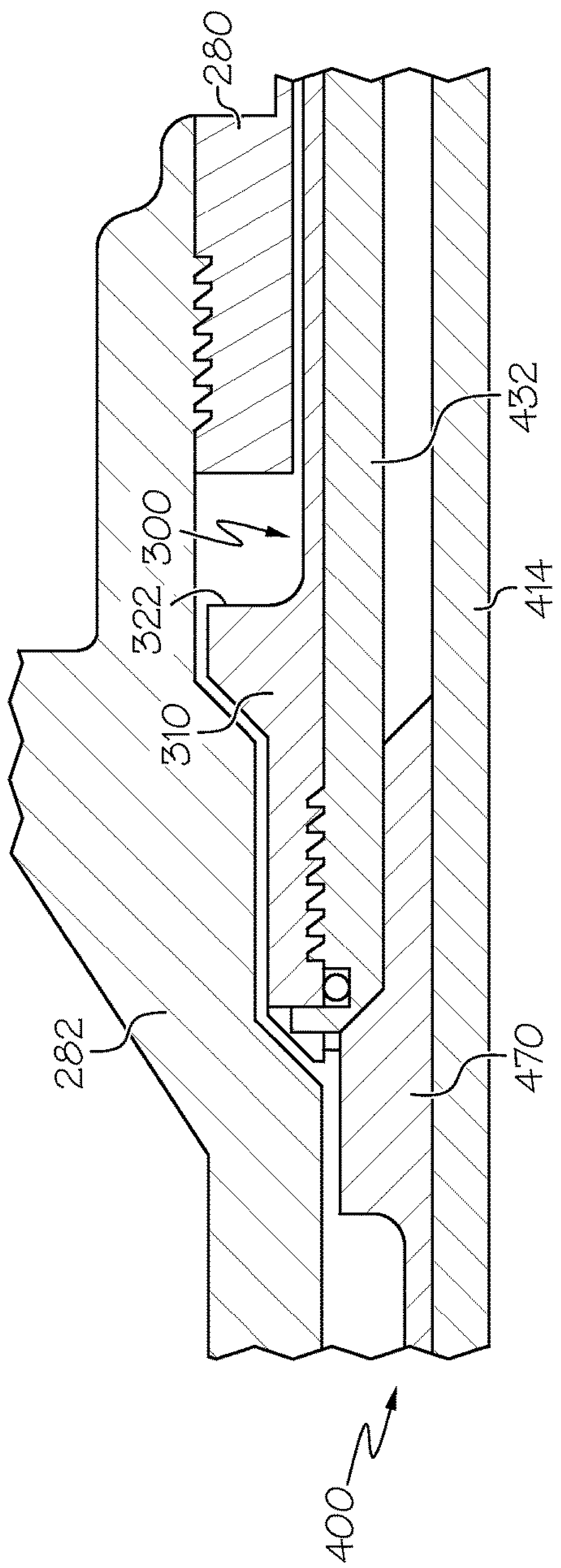

FIG. 14

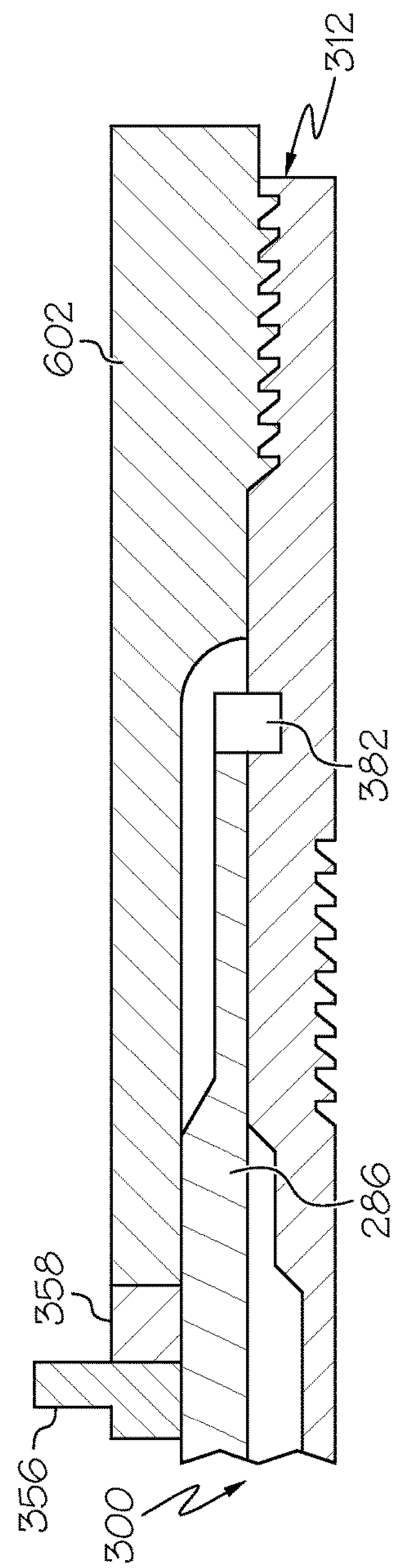

FIG. 15

GAS TURBINE ENGINES WITH INTERNALLY STRETCHED TIE SHAFTS

TECHNICAL FIELD

The following discussion generally relates to gas turbine engine systems and methods, and more particularly, to systems and methods associated with a tie shaft of a gas turbine engine.

BACKGROUND

A gas turbine engine may be used to power various types of vehicles and systems, including aircraft. A typical gas turbine engine may include, for example, a compressor section, a combustion section, a turbine section, and an exhaust section. During operation, the compressor section raises the pressure of inlet air, and the compressed air is mixed with fuel and ignited in the combustion section. The high-energy combustion gases flow through the turbine section, thereby causing rotationally mounted turbine blades to rotate and generate energy. The air exiting the turbine section is exhausted from the engine via the exhaust section. Energy extracted by the turbine section may drive the fans, compressors, power gearboxes, generators, and other external devices.

Many gas turbine engines include multiple stages of compressors and turbines arranged in series. For example, a conventional two-stage gas turbine engine includes, in flowpath order: a fan and/or a low pressure compressor, a high pressure compressor, a combustor, a high pressure turbine, and a low pressure turbine and/or power turbine. Two or more these components may be considered a rotating group that share a common tie shaft that imparts an axial force to maintain the position and alignment of the rotating components. Generally, however, given the complex structure and function of the various components associated with the tie shaft, it may be challenging or impossible to assemble and disassemble selected components without complete disassembly of the rotating group.

This is particularly an issue because certain engine components may require more frequent cleaning, repair, and disassembly than other components. For example, combustors and high pressure turbine vanes and blades often require more frequent maintenance than high pressure compressor vanes and rotors. Service issues may be further complicated by recent advancements in gas turbine engine technology involving reduced physical size and increased speeds and temperatures that make the conventional mechanisms for accessing the components associated with the tie shaft more challenging.

Accordingly, it is desirable to provide gas turbine engines that enable a more efficient manner for selective assembly and disassembly of components while meeting the mechanical limitations of current engine requirements. Furthermore, other desirable features and characteristics of the present invention will become apparent from the subsequent detailed description of the invention and the appended claims, taken in conjunction with the accompanying drawings and this background of the invention.

BRIEF SUMMARY

In an exemplary embodiment, a tie shaft for a rotating group of an engine core includes a cylindrical body having an internal surface and an external surface and extending between a forward end and an aft end. The tie shaft further

includes a first group of internal grooves on the internal surface of the cylindrical body proximate to the forward end and a second group of internal grooves on the internal surface of the cylindrical body proximate to the aft end.

In another exemplary embodiment, a rotating assembly for a gas turbine engine includes at least two rotating group components defining a bore and a tie shaft extending through the bore and axially retaining the at least two rotating group components during operation of the gas turbine engine. The tie shaft has a forward end and an aft end and defining an interior surface. The tie shaft includes a first at least one internal groove on the interior surface at the forward end and a second at least one internal groove on the interior surface at the aft end.

In a further exemplary embodiment, a method is provided for servicing an engine assembly with a rotating group axially retained by a tie shaft. The method includes inserting a stretch tool assembly through the tie shaft; exerting an outward axial force on the interior surface of the tie shaft at a forward end and at an aft end to stretch the tie shaft to axially decouple the tie shaft from the rotating group; and removing at least one component of the rotating group from the tie shaft.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will hereinafter be described in conjunction with the following drawing figures, wherein like numerals denote like elements, and wherein:

FIG. **1** is a simplified cross-sectional side view of a gas turbine engine according to an exemplary embodiment;

FIG. **2** is a partial cross-sectional view of high pressure core retained by a tie shaft suitable for use with the engine of FIG. **1** in accordance with an exemplary embodiment;

FIG. **3** is an isometric view of a tool assembly in accordance with an exemplary embodiment; and

FIGS. **4-15** are partial isometric and/or cross-sectional views of the tie shaft of FIG. **2** and the tool assembly of FIG. **3** during a disassembly procedure in accordance with an exemplary embodiment.

DETAILED DESCRIPTION

The following detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. Furthermore, there is no intention to be bound by any theory presented in the preceding background or the following detailed description.

Broadly, exemplary embodiments discussed herein include gas turbine engines with improved modularity. In particular, the tie shaft of a gas turbine engine may have features that enable engagement with a tool assembly such that components retained by the tie shaft may be assembled and disassembled in a more efficient manner. In one exemplary embodiment, the tie shaft includes internal grooves that enable the tie shaft to be internally stretched by the tool assembly.

FIG. **1** is a simplified, cross-sectional view of a gas turbine engine **100** according to an embodiment. The engine **100** may be disposed in an engine case **110** and may include a compressor section **130**, a combustion section **140**, a turbine section **150**, and an exhaust section **160** mounted on a shaft assembly **170**. The compressor section **130** may include a series of compressors that raise the pressure of the air entering the engine **100**. The compressors then direct the compressed air into the combustion section **140**. In the combustion section **140**, the high pressure air is mixed with fuel and combusted. The combusted air is then directed into the turbine section **150**.

The turbine section **150** may include a series of turbines disposed in axial flow series. The combusted air from the combustion section **140** expands through and rotates the turbines prior to being exhausted through the exhaust section **160**. In one embodiment, the turbines rotate to drive equipment in the engine **100** via concentrically disposed shafts or spools within the shaft assembly **170**. Specifically, the turbines may drive the compressors via one or more rotors. FIG. **1** depicts one exemplary configuration, and other embodiments may have alternate arrangements. The exemplary embodiments discussed herein are not limited to use in conjunction with a particular type of turbine engine.

FIG. **2** is a more detailed partial cross-sectional view of the shaft assembly **170** and portions of the compressor section **130**, the combustion section **140**, and the turbine section **150** of the engine **100** of FIG. **1** in accordance with an exemplary embodiment. In FIG. **2**, only half the cross-sectional view of the shaft assembly **170** is shown; the other half would be substantially rotationally symmetric about a centerline and axis of rotation **200**. Additionally, certain aspects of the engine **100** may not be shown in FIG. **2**, or only schematically shown, for clarity in the relevant description of exemplary embodiments. As noted above, the compressor and turbine sections **130**, **150** may have multiple stages. In the view of FIG. **2**, the compressor section **130** may include a high pressure compressor **132** immediately upstream of the combustion section **140**, and the turbine section **150** may include a high pressure turbine **152** immediately downstream of the combustion section **140**. As described in greater detail below, the high pressure compressor **132**, the combustion section **140**, and the high pressure turbine **152** may collectively be referred to as a high pressure core **202**.

Generally, the high pressure compressor **132** defines a flow path **230** and includes one or more stator assemblies **232**, **236**, **239** and rotor assemblies **234**, **237**. The stator assemblies **232**, **236**, **239**, **241** are stationary and function to direct the air through the flow path **230**. Typically, the compressor rotor assemblies **234**, **237** include one or more rotor disks **238**, **242**, each with a circumferential series of rotor blades **240**, **244** extending into the flow path **230**. As the rotor blades **240**, **244** rotate, air flowing through the flow path **230** is compressed. As noted above, the compressor rotor assemblies **234**, **237** may be driven by the turbine section **150** via the shaft assembly **170**.

As also noted above, the compressed air from the compressor section **130** is mixed with fuel and ignited in a combustor **142** of the combustion section **140** to generate high energy combustion gases that are directed into the turbine section **150**, particularly the high pressure turbine **152**. The high pressure turbine **152** generally includes one or more turbine stator assemblies (or nozzles) **254** and one or more turbine rotor assemblies **256**. Each turbine rotor assembly **256** includes a turbine rotor disk **258** with a circumferential series of turbine rotor blades **260** extending from the turbine rotor disk **258**. As the combustion gases flow through the high pressure turbine **152**, the rotor blades **260** rotate to drive the rotor disk **258**, which in turn, is coupled to the shaft assembly **170** to drive various components, such as the high pressure compressor **132**.

The shaft assembly **170** includes a tie shaft **300** that functions to axially retain the rotating components of the high pressure core **202**, particularly the compressor rotor assemblies **234**, **237** of the high pressure compressor **132** and the turbine rotor assembly **256** of the high pressure turbine **152**. The tie shaft **300** may also retain various other components, such as bearings **354**; seals **352**, **356**; shaft components **282**, **286**; shims **358**; and/or other components as needed. Collectively, the retained components associated with the tie shaft **300** may be referred to as a component group or rotating component group. The components of the component group are maintained radially concentric to one another, while in one exemplary embodiment, the tie shaft **300** provides only the axial load necessary to retain the relative positions.

In addition to the tie shaft **300**, the shaft assembly **170** may include one or more components that facilitate the transfer of torque within the rotating group. These components may be generally referred to as a power shaft assembly (portions of which are shown in FIG. **2**) and are typically positioned concentric to the tie shaft **300**. In particular, a forward shaft component **282** functions to couple the tie shaft **300** to other components of the power shaft assembly and rotating group components for common rotation during operation, as described below. However, during an assembly or disassembly operation, the tie shaft **300** may be decoupled from the forward shaft component **282** to enable independent rotation, as also described below.

As further described below, the tie shaft **300** is typically "stretched" upon installation or service by a tension force on the tie shaft **300** to result in the decoupling of the tie shaft **300** and rotating group components to enable assembly and/or disassembly. Additionally, upon release of this tension force, the tie shaft **300** exerts the above-referenced inward axial force on the components to maintain the relative positions and alignments during operation. The discussion below particularly details the structure of tie shaft **300** and systems and methods for stretching the tie shaft **300** such that, during the stretching operation, portions of the high pressure core **202** may be assembled and disassembled, and upon completion of the stretching operation, the inward axial retention force is applied in preparation for engine operation. In particular, the high pressure turbine rotor assembly **256** portion may be more easily removed for maintenance, thereby also providing access to the high pressure turbine nozzle **254** and combustor **142**, as needed. In the discussion below, the "stretching" operation refers to the preparation, installation and/or application of the tension force resulting in the inward axial retention force and/or assembly or disassembly for servicing.

As shown, the tie shaft **300** has a cylindrical body **302** extending from a first (or forward) end **310** to a second (or aft) end **312** through a collective bore **206** generally defined by the annular nature of the high pressure core **202**. In one exemplary embodiment, the first and second ends **310**, **312** are arranged and positioned such that the entire tie shaft **300** is considered to be completely internal to the rotating component group of the high pressure core **202**. In other words, the first end **310** of the tie shaft **300** is aft of the forward end of the most forward rotating component, which in the depicted exemplary embodiment is shaft component **282**. On the other side, the second end **312** is forward of the aft end of the most aft rotating component, which in the depicted exemplary embodiment is turbine rotor assembly **256** of the high pressure turbine **152**. As a result of this arrangement, no axial face of the tie shaft **300** may be accessible by tooling for the stretching operation. In other exemplary embodiments, the tie shaft **300** may extend beyond the ends of the rotating components.

The first end **310** of the tie shaft **300** has a protrusion **320** that forms an axial face **322** facing the aft direction. The axial face **322**, in the position shown, is pressed against a collar **280**, which in turn is coupled to shaft component **282**, introduced above. When the tie shaft **300** is in the position shown in FIG. **2**, the tie shaft **300** axially retains the rotating group components via the interface formed by the axial face **322** and collar **280**.

The shaft component **282** and/or collar **280** may define a recess **284** to accommodate the protrusion **320** and first end **310** of the tie shaft **300**. The recess **284** may be sized to additionally accommodate some amount of axial movement of the first end **310** of the tie shaft **300**. As described below, during the stretching operation, the tie shaft **300** is stretched such that the first end **310** moves in an axial forward direction, and as a result of this movement, the axial face **322** may separate from the collar **280**. Upon separation, the tie shaft **300** is rotationally decoupled from the compressor rotor assembly **234** and may rotate separately from other components of the shaft assembly **170**. In other words, upon separation of the axial face **322** and collar **280**, there is no feature that restricts rotation of tie shaft **300** relative to shaft component **282**.

The cylindrical body **302** of the tie shaft **300** defines an external (or outer) surface **304** and an internal (or inner) surface **306** that forms an internal bore **308**. The external surface **304** of the tie shaft **300** includes external threads **324** at the second end **312** upon which the turbine rotor assembly **256** is mounted with corresponding threads. As described below, the turbine rotor assembly **256** may be removed from the tie shaft **300** by counter-rotating the tie shaft **300** and turbine rotor assembly **256** to uncouple the threaded engagement. A retaining ring **382** may also be positioned on the external surface **304** to assist disassembly.

The internal surface **306** of the tie shaft **300** defines a first set of internal grooves (or rings) **330** proximate to the first end **310** and a second set of internal grooves **332** proximate to the second end **312**. As described in greater detail below, the internal grooves **330**, **332** enable engagement with a tool assembly that may be used to stretch the tie shaft **300** and assemble and/or disassemble the high pressure core **202** relative to the tie shaft **300**. One or both sets of the grooves **330**, **332** may be concentric, e.g. separate circumferential grooves, such that control of the angular position of the tool assembly is not required. Furthermore, each of the grooves **330**, **332** may be shaped such that the load capability is increased in the desired direction consistent with the application of stretch tool load. In other words, the wall of the respective groove on the side of the desired direction (e.g., the forward side wall of grooves **330** and the aft side wall of grooves **332**) may be angled inward or perpendicular to a radial plane to enhance load bearing characteristics, although other configurations and groove shapes are possible. In one exemplary embodiment, the shape of the grooves **330**, **332** may closely resemble the shape of buttress threads, albeit formed as separate, concentric circumferential grooves, rather than the typical, helical, threaded form. As such, in some embodiments, the grooves **330**, **332** may be referred to as buttress rings. In alternate embodiments, the grooves **330**, **332** may have such a helical or threaded form. In the depicted embodiment, the grooves **330**, **332** are formed within the internal surface **306**, although in other embodiments, the grooves **330**, **332** may be formed by lands extending from the internal surface **306**.

The tie shaft **300** may further include one or more internal slots **340**, **342** extending from the internal surface **306** into or through the body **302**. In one exemplary embodiment, the tie shaft **300** may have a first circumferential series or row of slots **340** proximate to the first set of internal grooves **330** and a second circumferential series or row of slots **342** proximate to the second set of internal grooves **332**. As described in greater detail below, the slots **340**, **342** enable rotatable coupling of the tie shaft **300** to the tool assembly as needed to assemble and/or disassemble the high pressure core **202** relative to the tie shaft **300**. An exemplary tool assembly will be introduced prior to a description of the engagement and function with respect to the tie shaft **300**.

Reference is made to FIG. **3**, which is a perspective view of a tool assembly **400** for engagement with a tie shaft (e.g., tie shaft **300** of FIG. **2**) in accordance with an exemplary embodiment. The tool assembly **400** includes a forward tool portion **410** and an aft tool portion **420**. As shown, each of the tool portions **410**, **420** has a cylindrical configuration, and the forward and aft tool portions **410**, **420** may have a telescoping, sliding engagement relative to one another.

In this exemplary embodiment, the forward tool portion **410** has a forward expander **470** and a main body **414**. Generally, the main body **414** extends the entire length of tool assembly **400** and includes segments or portions that are sized to accommodate concentric, axial movement relative to the aft tool portion **420** and the aft expander **480**. As described below, the aft tool portion **420** includes an aft tool body **459** and an aft expander **480**. The aft tool body **459** and aft expander **480** are sized such that the aft tool body **459** slides over a portion of the main body **414** and the aft expander **480** slides over the aft tool body **459**.

As also shown in FIG. **3**, the tool assembly **400** further includes two or more jaw members **432** that form a forward jaw set **430** on the outer periphery of the main body **414**. In one exemplary embodiment, the forward jaw set **430** includes three jaw members **432**, although any suitable number may be provided. Each jaw member **432** of the forward jaw set **430** has a first end **434** mounted to the main body **414** at a hinge **438** and a second end **436** with outer circumferential grooves **440**. At each hinge **438**, the respective jaw member **432** is mounted to pivot between expanded and collapsed positions.

As described below, the outer circumferential grooves **440** of the forward jaw set **430** are configured to match and mate with the forward internal grooves **330** of the tie shaft **300** (FIG. **2**) when the jaw members **432** are in the expanded position. In some embodiments, one or more of the forward jaw members **432** may include pins that engage, in the expanded position, with corresponding slots **340** in the tie shaft **300** (FIG. **2**), as discussed below. Moreover, in some exemplary embodiments, the jaw members **432** may have a ring groove and a retaining ring (or o-ring) arranged within the ring groove, as more clearly shown in subsequent views. Such a retaining ring functions to bias the jaw members **432** of the forward jaw set **430** into the collapsed position.

The tool assembly **400** further includes one or more jaw members **452** that form an aft jaw set **450** on the outer periphery of the aft tool portion **459**. In one exemplary embodiment, the aft jaw set **450** includes three jaw members **452**, although any suitable number may be provided. Each jaw member **452** of the aft jaw set **450** has a first end **454** mounted to the aft tool portion **420** at a hinge **458** and a second end **456** with outer circumferential grooves **460**. Similar to the forward jaw set **430**, each respective jaw member **452** is mounted to pivot at the respective jaw hinge **458** between expanded and collapsed positions.

As described below, the outer circumferential grooves **460** of the aft jaw set **450** are configured to match and mate with the aft internal grooves **332** of the tie shaft **300** (FIG. **2**) when the jaw members **452** are in the expanded position. In some embodiments, one or more of the aft jaw members

452 may include pins that engage, in the expanded position, with corresponding slots **342** in the tie shaft **300** (FIG. **2**), as discussed below. Moreover, in some exemplary embodiments, the jaw members **452** may have a ring groove and a retaining ring (or o-ring) arranged within the ring groove, as more clearly shown in subsequent views. Such a retaining ring functions to bias the jaw members **452** of the aft jaw set **450** into the collapsed position. In some exemplary embodiments, the grooves **440**, **460** may be considered buttress rings, and in further exemplary embodiments, the grooves **440**, **460** may be threaded or helical. Generally, as used herein with respect to grooves **330**, **332**, **440**, **460**, the term "grooves" may refer to both threaded or helical arrangements and concentric arrangements.

As introduced above, the tool assembly **400** further includes forward and aft expanders **470**, **480**. The forward expander **470** is generally cylindrical with a slightly larger diameter than the main body **414** of the forward tool portion **410**. During the stretching operation, as described in greater detail below, the forward expander **470** slides over the forward end of the main body **414** and the leading edge slips between the jaw set **430** and the outer surface of the main body **414**. As a result of this movement, the jaw members **432** are pivoted from the collapsed position to the expanded position.

The aft expander **480** functions in a similar manner as the forward expander **470**. The aft expander **480** is generally cylindrical with a slightly larger diameter than the aft tool body **459**. During the stretching operation, as described in greater detail below, the aft expander **480** slides over the aft end of the aft tool body **459** and the leading edge slips between the aft jaw set **450** and the outer surface of the aft tool body **459**. As a result of this movement, the jaw members **452** are pivoted from the collapsed position to the expanded position.

The tool assembly **400** further includes forward and aft retention members **490**, **492**. The forward and aft retention members **490**, **492** are internally threaded nut-type members. In one exemplary embodiment, the forward retention member **490** engages the forward end of the main body **414** of the forward tool portion **410** to retain the axial position of the forward expander **470**. Similarly, the aft retention member **492** engages the aft end of the aft tool portion **459** to retain the axial position of the aft expander **480**.

Now that the tie shaft **300** and tool assembly **400** have been introduced in FIGS. **2** and **3**, additional details about stretching operation, including disassembling and assembling the high pressure core **202**, will now be provided with reference to FIGS. **4-15**. Generally, the views of FIGS. **4-15** and the associated discussion below are presented in the sequence of a disassembly operation, while the sequence of an assembly operation is reversed.

FIG. **4** is a partial perspective view of the tool assembly **400**. Generally, FIG. **4** depicts portions of the tool assembly **400** as the tool assembly itself is assembled and deployed relative to the tie shaft **300** (FIG. **3**). In FIG. **4**, the surrounding tie shaft **300** and other engine components are omitted for clarity. Initially, during deployment for the stretching operation, the main body **414** of the forward tool portion **410** is inserted through the bore **308** of the tie shaft **300** (FIG. **2**) with the forward jaw set **430** in the collapsed position. Although the tie shaft **300** is omitted in FIG. **4**, the main body **414** is generally positioned within the tie shaft **300** such that the circumferential grooves **440** of the forward jaw set **430** are approximately radially aligned with the internal grooves **330**, as more clearly shown and described with reference to FIGS. **5** and **6**.

FIG. **5** is a further view depicting a partial perspective view of the tool assembly **400** during deployment subsequent to the view of FIG. **4**. Like FIG. **4**, the surrounding tie shaft **300** and other engine components are omitted for clarity in FIG. **5**. In FIG. **5**, the forward expander **470** is inserted onto the main body **414** from the forward side. FIG. **6** is a more detailed cross-sectional view of the forward expander **470** being inserted along the main body **414** of the tool assembly **400**, and additionally shows aspects of the engine **100**, particularly portions of the tie shaft **300** and shaft component **282**. As shown in FIG. **6**, the forward expander **470** has a beveled and angled leading edge **472**, and the jaw members **432** of the forward jaw set **430** have corresponding beveled and angled leading edges **442** such that the forward expander **470** passes between the jaw members **432** and the main body **414** as the forward expander **470** advances along the forward end of main body **414**.

FIG. **7** is a further view depicting a partial perspective view of the tool assembly **400** during deployment subsequent to the view of FIGS. **5** and **6**. In FIG. **7**, the surrounding tie shaft **300** and other engine components are omitted for clarity. As shown, the forward expander **470** has been advanced such that forward expander **470** positioned between the jaw members **432** and the main body **414**. As a result of this position, the jaw members **432** have been urged into the expanded position. Upon reaching the appropriate axial position, the forward expander **470** may be secured by the forward retention member **490**, which is screwed onto the forward end of the main body **414**. FIG. **8** is a more detailed cross-sectional view of the main body **414** and the forward retention member **490** in these positions relative to the tie shaft **300**. As shown in FIG. **8**, in the expanded position, the circumferential grooves **440** engage with the forward internal grooves **330** on the internal surface **306** of the tie shaft **300**. Additionally, FIG. **8** more clearly depicts the pins **444** on the jaw members **432** that engage the slots **340** on the forward end **310** of the tie shaft **300**. In this position, the forward end **310** of the tie shaft **300** is rotationally coupled to the tool assembly **400** as a result of the engagement between the pins **444** on the jaw members **432** and the slots **340** of the tie shaft **300** and additionally axially coupled to the tool assembly **400** as a result of the engagement between the circumferential grooves **440** of the jaw members **432** and the forward internal grooves **330** on the tie shaft **300**.

FIG. **8** additionally depicts the ring groove **446** on the jaw members **432** and the retaining ring **448** extending within the ring groove **446**. As noted above, the retaining ring **448** functions to bias the jaw members **432** into the collapsed position until being forced into the expanded position by the forward expander **470**.

FIG. **9** is a further view depicting a partial perspective view of the tool assembly **400** during deployment subsequent to the view of FIGS. **7** and **8**. In FIG. **9**, the surrounding tie shaft **300** and other engine components are omitted for clarity. As shown, the aft tool portion **420** is inserted into the bore **308** of the tie shaft **300** (not shown in FIG. **9**) from the aft side. As shown, the aft tool body **459** is inserted around and along the aft end of the main body **414**. The aft tool body **459** is inserted with the aft jaw set **450** in a collapsed portion. The main body **414** may have an expanded diameter stop member **449** to provide an indication of the proper position of the aft tool body **459** relative to the forward tool portion **410**. Although the tie shaft **300** is omitted in FIG. **9** for clarity, the aft tool body **459** is generally positioned within the tie shaft **300** such that the circumferential grooves **460** of the aft jaw set **450** are approximately radially aligned with the internal grooves **332**, as more clearly shown and described below with reference to FIG. **11**.

FIG. **10** is a further view depicting a partial perspective view of the tool assembly **400** during deployment subsequent to the view of FIG. **9**. In FIG. **10**, the surrounding tie shaft **300** and other engine components are omitted for clarity. The aft expander **480** is inserted into the bore **308** of the tie shaft **300** (FIG. **11**) from the aft side onto the aft tool body **459**. FIG. **11** is a more detailed cross-sectional view of the aft expander **480** being inserted along the aft tool body **459**. As shown in FIG. **11**, the aft expander **480** has a beveled and angled leading edge **482**, and the jaw members **452** of the aft jaw set **450** have corresponding beveled and angled leading edges **462** such that the aft expander **480** passes between the jaw members **452** and the aft tool body **459** as the aft expander **480** advances along the aft tool body **459**.

FIG. **12** is a further view depicting a partial perspective view of the tool assembly **400** during deployment subsequent to the view of FIGS. **10** and **11**. In FIG. **12**, the surrounding tie shaft **300** and other engine components are omitted for clarity. As shown, the aft expander **480** has been advanced such that aft expander **480** is positioned between the jaw members **452** and the aft tool portion **459**. As a result of this position, the jaw members **452** have been urged into the expanded position. Upon reaching the appropriate axial position, the aft expander **480** is secured in this position by the aft retention member **492**, which is screwed onto the aft tool body **459**. FIG. **13** is a partial, more detailed cross-sectional view of the aft tool portion **420** and the aft retention member **492** in these positions relative to the tie shaft **300**. As shown in FIG. **13**, in the expanded position, the circumferential grooves **460** on the aft jaw set **450** engage with the aft internal grooves **332** on the internal surface **306** of the tie shaft **300**.

Additionally, FIG. **13** more clearly depicts the pins **464** on the jaw members **452** that engage the slots **342** on the aft end **312** of the tie shaft **300**. In this position, the aft end **312** of the tie shaft **300** is rotationally coupled to the tool assembly **400** as a result of the engagement between the pins **464** of the jaw members **452** and the slots **342** of the tie shaft **300** and additionally axially coupled to the tool assembly **400** as a result of the engagement between the circumferential grooves **460** of the jaw members **452** and the aft internal buttress rings **332** on the tie shaft **300**.

FIG. **13** additionally depicts the ring groove **466** on the jaw members **452** and the retaining ring **468** extending within the ring groove **466**. As noted above, the retaining ring **468** functions to bias the jaw members **452** into the collapsed position until being forced into the expanded position by the aft expander **480**.

As such, in the position depicted in FIGS. **12** and **13**, the tool assembly **400** is engaged with the tie shaft **300** via both sets of internal grooves **330**, **332**. In this position, as partially shown in FIG. **13**, the main body **414** extends beyond the aft end of the aft tool portion **420**. In this position, a hydraulic ram (not shown) or other equipment may be used to press the main body **414** in a forward direction from the aft end, as represented by arrow **500**. At the same time, the aft tool body **459** is pulled in an aft direction or maintained in position at the aft retention member **492**, as indicated by arrow **502**. As a result of these forces **500**, **502**, the main body **414** and aft tool body **459** are translated relative to each other such that the total length of the tool assembly **400** is increased. Since the forward and aft tool portions **410**, **420** are engaged with the internal grooves **330**, **332** of the tie shaft **300**, the lengthening of the tool assembly **400** functions to stretch the tie shaft **300** in the axial direction.

FIG. **14** is a partial cross-sectional view of the stretched tie shaft **300** at the forward end **310**. As the tie shaft **300** is stretched, the axial face **322** separates from the collar **280**, thereby decoupling the tie shaft **300** from the collar **280** and other portions of the rotating components, including the compressor rotor assembly **234**, such that the tie shaft **300** may rotate independently.

Upon separation, a first rotating tool (not shown) may be inserted to counter-rotate the high pressure turbine rotor assembly **256** (e.g., FIG. **13**), and consequently, the power shaft assembly, and a second rotating tool (not shown) may be used to rotate the tool assembly **400**, and consequently, the tie shaft **300**. The first and second rotating tools may be any suitable tooling components, including wrenches or tangs. In one exemplary embodiment, the second rotating tool may be formed by tangs on the reaction tool represented by force **502** (FIG. **13**). As noted above, for example, in the description of FIG. **2**, the high pressure turbine rotor assembly **256** has a threaded or screw engagement with the tie shaft **300**. As a result of the relative rotations, the high pressure turbine rotor assembly **256** is decoupled from the tie shaft **300** and may be removed from the aft end **312**. As noted above, the retaining ring **382** (FIG. **2**) may be employed to retain the positions of the rotating group components in this position.

FIG. **15** is a partial cross-sectional view of the remaining components of the high pressure core **202** and tie shaft **300** after removal of the high pressure turbine rotor assembly **256** (see, e.g., FIG. **13**). In this position, a rotor group retention member **602** may be installed on the aft end **312** of the tie shaft **300** to secure the remaining portions of the high pressure core **202**, either temporarily or for storage. The rotor group retention member **602** may be a nut-type attachment with threads that engage the threads that previously retained the removed turbine rotor assembly **256**. As a result, the high pressure turbine rotor assembly **256** may be removed and the remainder of the rotating group of the high pressure core **202** may remain intact or subject to further disassembly. In this position, the turbine nozzle **254** and liner of the combustor **142** may also be removed.

In one exemplary embodiment and referring to FIGS. **3-15**, the tool assembly **400** may be removed by decoupling the aft retention member **492**, then removing the aft expander **480**, then removing the aft tool body **459**, then removing forward retention member **490**, then removing the forward expander **470**, and then removing the main body **414**.

As a result of the interaction between the tie shaft **300** and tool assembly **400**, assembly and disassembly do not require any design changes in disk bore diameters relative to previous arrangements to enable modular disassembly of more efficient maintenance. Although the tie shaft **300** and tool assembly **400** are described above with respect to a high pressure core, exemplary embodiments discussed above may be implemented with any type of rotating group and/or rotor assembly. For example, exemplary embodiments of the shaft assembly and tool assembly described above may be used in a rotating group with only two members, including only two compressor assemblies or only two turbine rotor assemblies. The exemplary embodiments discussed above provide modularity capability for more efficient assembly and disassembly of selective components, particularly without requiring complete disassembly of the gas turbine engine. Exemplary embodiments are applicable to both commercial and military gas turbine engines and auxiliary power units. Moreover, exemplary embodiments may find beneficial uses in many industries, including aerospace and particularly in high performance aircraft, as well as automotive, marine and power generation.

While at least one exemplary embodiment has been presented in the foregoing detailed description of the invention, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the invention in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing an exemplary embodiment of the invention. It being understood that various changes may be made in the function and arrangement of elements described in an exemplary embodiment without departing from the scope of the invention as set forth in the appended claims.

What is claimed is:

1. A tie shaft for a rotating group of an engine core, comprising:
- a cylindrical body having an internal surface and an external surface and extending between a forward end and an aft end;
- a first group of internal grooves on the internal surface of the cylindrical body proximate to the forward end; and
- a second group of internal grooves on the internal surface of the cylindrical body proximate to the aft end,
- wherein the cylindrical body includes at least one set of slots extending from the internal surface proximate to at least one of the first group of internal grooves and the second group of internal grooves.

2. The tie shaft of claim **1**, wherein the first group of internal grooves is a first group of buttress rings, and wherein the second group of internal grooves is a second group of buttress rings.

3. The tie shaft of claim **2**, wherein the first group of buttress rings and the second group of buttress rings are concentric, circumferential rings.

4. The tie shaft of claim **2**, wherein each of the first group of buttress rings includes a first surface that engages a first axial load in a first direction, and wherein each of the second group of buttress rings includes a second surface that engages a second axial load in a second direction.

5. The tie shaft of claim **1**, wherein the first group of internal grooves is configured to engage a first stretch load in a first direction and the second group of internal grooves is configured to engage a second stretch load in a second direction.

6. The tie shaft of claim **1**, wherein the external surface of the cylindrical body is free from axial surfaces configured to engage an axial stretch load.

7. A rotating assembly for a gas turbine engine, comprising:
- at least two rotating group components defining a bore; and
- a tie shaft extending through the bore and axially retaining the at least two rotating group components during operation of the gas turbine engine, the tie shaft having a cylindrical body with a forward end and an aft end and defining an interior surface,
  - wherein the tie shaft comprises a first at least one internal groove on the interior surface of the cylindrical body at the forward end and a second at least one internal groove on the interior surface of the cylindrical body at the aft end, wherein the cylindrical body includes at least one set of slots extending from the internal surface proximate to at least one of the first at least one internal groove and the second at least one internal groove.

8. The rotating assembly of claim **7**, wherein the tie shaft is configured to receive a stretch load from a stretch tooling assembly via the first at least one internal groove and the second at least one internal groove.

9. The rotating assembly of claim **8**, wherein the tie shaft is only configured to receive the stretch load from the stretch tooling assembly via the first at least one internal groove and the second at least one internal groove.

10. The rotating group of claim **7**, wherein the at least two rotating group components include at least two compressor rotor assemblies.

11. The rotating group of claim **7**, wherein the at least two rotating group components include at least one compressor rotor assembly and at least one turbine rotor assembly.

12. The rotating group of claim **7**, wherein the gas turbine engine includes a compression section and a turbine section such that the at least one compressor rotor assembly includes a first compressor rotor assembly at a forward-most position in the compression section and the at least one turbine rotor assembly includes a first turbine rotor assembly at an aft-most position in the turbine section, and wherein the forward end of the tie shaft terminates aft of a forward-most point of the first compressor rotor assembly and the aft end of the tie shaft terminates forward of an aft-most portion of the second turbine rotor assembly.

13. The rotating group of claim **7**, wherein the first at least one internal groove comprises a first group of buttress rings, and wherein the second at least one internal groove comprises a second group of buttress rings.

14. The rotating group of claim **13**, wherein the first group of buttress rings and the second group of buttress rings are concentric, circumferential rings.

15. The rotating group of claim **7**, wherein the first at least one internal groove is configured to engage a first stretch load in a first direction and the second at least one internal groove is configured to engage a second stretch load in a second direction.

16. A method for servicing an engine assembly with a rotating group axially retained by a tie shaft, the tie shaft comprising a cylindrical body having an internal surface and an external surface and extending between a forward end and an aft end; a first group of internal grooves on the internal surface of the cylindrical body proximate to the forward end; and a second group of internal grooves on the internal surface of the cylindrical body proximate to the aft end,
- the method comprising the steps of:
- inserting a stretch tool assembly through the tie shaft;
- exerting an outward axial force on the internal surface of the tie shaft at the forward end and at the aft end to stretch the tie shaft to axially decouple the tie shaft from the rotating group;
  - wherein the exerting step includes exerting the outward axial force at the forward end via the first group of internal grooves and at the aft end via the second group of internal grooves, and
  - wherein the inserting step comprises:
  - inserting a tool main body of the tool assembly through a bore of the tie shaft, the tool assembly further including a first set of jaw members on the tool main body with a first set of circumferential grooves, wherein the tool main body portion is inserted into the bore of the tie shaft with the first set of jaw members in a collapsed position;

expanding the first set of jaw members on the forward tool portion into an expanded position such that the first set of circumferential grooves on the first set of jaw members engage the first group of internal grooves;

inserting an aft tool portion through the bore of the tie shaft, the aft tool portion including a second set of jaw members having a second set of circumferential grooves, wherein the aft tool portion is inserted into the bore of the tie shaft with the second set of jaw members in a collapsed position; and

expanding the second set of jaw members on the aft tool portion into an expanded position such that the second set of circumferential grooves on the second set of jaw members engage a second group of internal grooves; and

removing at least one component of the rotating group from the tie shaft.

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